# Optical quantum computer based on RDS crystal

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**Abstract**

We have proposed the construction of optical quantum computer (OQC) on regular domain structure (RDS) crystal. By using RDS crystal, we can perform all the logical operations on one RDS crystal. Moreover, RDS crystals are parctically independent to the heating effects [4] i.e., can perform logic operations constantly without cooling the RDS crystal [4]. Also, we have proposed the quantum parallelsim i.e., parallel coherent laser beams are injected at the input of the RDS crystals. By using the RDS crystal we can perform the reduce the requirements of the linear and nonlinear optical components.

## 1 Introduction

The physics of quantum computation and information [2] is one of the branch of quantum theory, which develops day by day very fast. A lot of proposals [2] have been proposed for the construction of quantum computer. Most reliable, some of them [2] are optical quantum computer (OQC), ion-trap, and solid-state quantum computer (SSQC). The most prospective technique to construct quantum computer among them is SSQC. So, throughuhout this paper, we will discuss the OQC and SSQC. Our dream to see the power, possibilities and applications of quantum computer is still under process. The reason for comparing the OQC with SSQC is that the coherent optical computers [1,6,7] which come around 1960 were studied very extensively in USA for their millitary purposes. The coherent optical computers were constructed with the huge amount of optical instruments and were useful for very limited number of problems. After the invention of the MASER, the requirement [1] for coherent optical computer starts increasing very fast with more requirements of linear and nonlinear optical instruments. Moreover, the applications, possibilities of coherent optical computer were very limited as compare to the digital computer based on Silicon. So, the coherent optical computers lost their interest [6-8] due to the huge amount of requirements and limited number of applications. In the begining of 1990, OQC [2,3,5,9] were proposed. In this article, we are studying the main technical requirements to construct OQC and comparing with SSQC. Moreover, firstly, we are proposing to construct OQC based on RDS crystals [4].

# 2 Quantum computer

## 2.1 Soild-state quantum computer (or SSQC)

The SSQC consists [2] of $n$ number of atoms in one molecule. Why we are taking one molecule and why not two or three? The reason for taking one molecule is that the interaction within the molecules are negligible as compare to interaction of atoms in each molecule. Some of the atoms in each molecule have nuclear spins 1/2 with slightly different resonance frequencies. To have an idea of SSQC, we will demonstrate the graphical representation of SSQC and how to perform logical operations on it. As an example we are taking one molecule having two atoms and each atom having nuclear spin 1/2 and resonance frequencies $\omega_1$ and $\omega_2$ (see fig.1).

### 2.1.1 Hamiltonian of the molecule having two nuclear spins

The two spins are interacting with each other with hyperfine interaction $j_{12}$. To start, the implementation of some quantum algorithm, firstly, we align the two nuclear spins of each molecule along the direction of constant magnetic field $B_0$, which is applied along the $z$-axis. The Hamiltonian of the system of two nuclear spins 1/2 with hyperfine interaction $j_{12}$ [2]

$$\hat{H} = B_0(\hat{\sigma}_{z1} + \hat{\sigma}_{z2}) + j_{12}\hat{\sigma}_{z1}\hat{\sigma}_{z2} \tag{1}$$

Where $\hat{\sigma}_{z1}$ and $\hat{\sigma}_{z2}$ are the Pauli matrices of nuclear spins $\hat{s}_1 = \frac{1}{2}\hat{\sigma}_1$ and $\hat{s}_2 = \frac{1}{2}\hat{\sigma}_2$. The logical operations are performed by the time dependent unitary operator

$$\hat{U}(t) = e^{-i\hat{H}t/\hbar} \tag{2}$$

We can change the dyanamics and position of spins $\hat{s}_1$ and $\hat{s}_2$ by selecting different resonance frequency impulses [2].

### 2.1.2 Quantum logic gates

Recently, it is shown that for the implementation of quantum algorithms on quantum computer, only two quantum logical gates (NOT and CNOT) [2] are needed. It means that the complex quantum algorithms can be executed on quantum computer with the combination of quantum logical gates NOT and CNOT (control-not). The true tables for quantum logical gates NOT and CNOT are as follows

Truth tables for logic gates NOT and CNOT:

| *NOT gate* | |
|---|---|
| Input $x$ | Output $y = \bar{x}$ |
| 0 | 0 |
| 0 | 1 |

| *CNOT gate* | | | |
|---|---|---|---|
| Input $x_1$ | Input $x_2$ | Output $y_1 = x_1$ | Output $y_2 = x_1 \oplus x_2$ |
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 1 | 1 |
| 1 | 1 | 1 | 0 |

Where bar over $\bar{x}$ and sign $\oplus$ denote the NOT operation and summation modulo 2.

### 2.1.3 Minimum requirements to construct SSQC

1. $2^n$-number of qubits (quantum bits) are required to operate and store data.

2. To prepare the system (qubits) to its initial state i.e., constant magnetic field is required to align the initial spin states along the magnetic field direction.

3. To isolate the quantum computer (qubits) from the environment (decoherence effect) [10], which is practically uncntrollable part of the quantum computer.

4. Unitary transformations to implement quantum algorithms i.e., for the implementations of quantum algorithms.

5. Quantum measurements [10], which are needed for measuring the final state of the implemented quantum algorithms.

## 2.2 Optical quantum computer (or OQC)

There are two proposals [2,3,5,9] to construct OQC on the basis of linear optics and nonlinear optics. The linear optics means that we need coherent laser beams, polarization beam splitters (PBS), polarization rotating plates, optical mirrors, photo-detectors etc. For the case of nonlinear optics we need nonlinear crystals and all the components of the linear optics.

#### 2.2.1 Case no.1

#### 2.2.2 OQC based on linear optics

The proposal to construct OQC based on linear optics was given by Spreeuw [9]. To perform quantum computation on OQC for the general case, we need exponentially amount of linear optical components. For example to have $2^n$ qubits as in the case of SSQC, we need at least $2^n$ number of optical components to have properties like SSQC at least. The exponentially number of components can be reduced by using polarized states (Jones matrices) of light.

#### 2.2.3 OQC qubits

The OQC 3 qubits can be represented by

$$|\phi>= a|0,0,0> +b|1,1,1> \tag{3}$$

To have (represent) three OQC qubits (3), we need 4 polarized light modes i.e., 4 Jones matrices [9]. But in SSQC we need $n = 3$ nuclear spins to have $2^3 = 8$ quantum states. PBS are required for separating horizontal and vertical polarization components of the laser mode.

#### 2.2.4 Why PBS?

For performing the logical operations. For example, the logical operations NOT and CNOT can be implemented by using the PBS.

#### 2.2.5 Linear optics logical gates

Mathematically, linear optics logical gates can be constructed by using $SU(2)$ and $SU(1,1)$ algebra [3]. Experimentally, it can be constructed by rotating the PBS (see fig.2).

#### 2.2.6 Case no.2

#### 2.2.7 OQC based on nonlinear optics

The proposal to construct logical gates based on nonlinear optics is given by Milburn [6,2]. This OQC uses nonlinear crystal to get the squeezed states of light (SSL). As we know the SSL has antibunching property i.e., the photons are uniformally distrubuted as compared to the coherent state of light. By using the antibunching property of SSL, this computer can

### 2.2.8 OQC qubits

In the case of SSL, the role of qubits perform the photons of SSL i.e., each photon of SSL represents, one optical qubit based on nonlinear optics.

### 2.2.9 Nonlinear optics logical gates [3,5]

To operate on each photon qubit, we need photo-detectors with high quantum efficieny, which are our dream of future. Moreover, in quantum mechanics, we detect the average number of physical quantities. It means, we do not have 100% gurantee that we have detected the concrete photon, which we planned. Again, we need the beam splitters to perform the logical operations, which are highly noisy.

### 2.2.10 Case no.3

### 2.2.11 OQC based on RDS (regular domain structure) crystal

OQC can be constructed at least on one nonlinear crystal. It means that $n$ number of laser beams are propagating through one nonlinear crytal (see fig. 2). Why we are using nonlinear crystal? There are some advantages to use nonlinear crytals:

1. logical gates (NOT and CNOT) can be performed by using the RDS (regular domain structure) crystals.
2. We can use the property of squeezed states of light, i.e., the quantum noise is less as compare to the coherent state of light.
3. RDS crystals are independent on heating [4] of the crystals. We can use this crystal without any cooling process, which will not delay our computation process.
4. ....

### 2.2.12 Logical gates based on RDS crystal

There are two ways to perform the logical operations in RDS crystals.

1. By using the properties of bistable switches i.e., the logical switch starts working when the intensity of the coherent laser beam (fundamental mode) propagating through the RDS crystal starts producing the predefined intensity of harmonic generation for some concrete logical operation.

2. Since, the RDS crystals can produce at a time multiple number of harmonic modes. We can predefine each harmonic for logic operations. For example, we can predefind second harmonic generation for NOT and third harmonic generation for CNOT logical operations.

# 3 Conclusion

If we will compare the properties of SSQC and OQC, we can conclude that the future of OQC is practically absent. Due to the requirement of huge number of optical components (linear and nonlinear), heating of the linear and nonlinear crystals and quantum noise is greater than the coherent state of light. The proposal which we have offered i.e., the construction of OQC on RDS crytals require less number of components as compare to linear and nonlinear (ordinary) crystals. Moreover, we can construct the logical gates on one RDS crytals with lesser quantum noise, because we are performing all the logic operations in it as compare to the linear and nonlinear crystals [2,3,5,9]. So, the OQC based on RDS is more realistic as compare to other proposals to construct OQC.

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Fig.1
Fig.2a
Fig.2b
Fig.3